Processing of images in a direction of succession

The invention relates to a method of processing images, in which

- individual images succeed one another in a direction of succession,
- a multi-dimensional data set is constructed from the individual images,
  - which multi-dimensional data set assigns data values to positions in a multi-
5   dimensional space,
  - which multi-dimensional space is set up by the direction of succession and two
    directions parallel to the surface of the individual images,
- a slice through the multi-dimensional data set is reconstructed along a cut plane through
  the multi-dimensional space, and
10 - the direction of the cut plane has a component in the direction of succession.

       Such a method of processing images is known from the article "Exploring the
discrimination power of the time domain for segmentation and characterisation of lesions in
serial MR data" by Guido Gerig et al. in "Medical image computing and computer-assisted
intervention", MICCAI '98 (W.M. Wells, A. Colchester, S. Delp, Eds., Springer 1998).

15   The known method is applied to a series of three-dimensional (3D-MR)
magnetic resonance reconstructions that succeed one another in time. Each of the 3D MR
reconstructions comprises a plurality of magnetic resonance images of different slices
through the 3D MR reconstruction. According to this known method the direction of
succession represents the succession in time of the magnetic resonance images. The
20 individual magnetic resonance images are formed with intervals that amount to a week or to a
month. Subsequently, the successive magnetic resonance images are combined so as to form
a four-dimensional (4D) (x,y,z; t) data set. In accordance with the known method a region of
interest is indicated in advance in the individual magnetic resonance images. More
specifically, each time the same lesion is indicated in the individual magnetic resonance
25 images. The lesions, that is the region of interest, in the successive magnetic resonance
images are registered relative to one another while compensating for motion between the
successive magnetic resonance images. The mutually registered magnetic resonance images
are combined so as to form the 4D data set.

In conformity with the known method the development in time of the lesion is studied by means of two-dimensional images of various profiles along lines through the 3D MR volume as a function of time. Each of these profiles represents, each time for a given spatial position, the variation in time of the brightness value in the relevant spatial position.

5   The set of such profiles for respective positions in the successive images constitutes a slice along a cut plane in the direction of time.

It is an object of the invention to locate the region of interest more accurately and in a simpler manner from the images.

This object is achieved in accordance with the invention in that a region of

10   interest is located on the basis of the cut plane.

The method in accordance with the invention is applied to a set of images in a given order of succession. The order of succession of the set of images is the direction in which the images succeed one another. For example, when the images have been acquired successively in time, the images are temporally successive images (images acquired later are

15   positioned behind previously acquired images) and the direction of succession is the time axis. It is also possible to use other directions of succession, for example, successive positions of two-dimensional slices through a three-dimensional volume, successive phases in a perfusion process, or successive values of acquisition parameters. Such an acquisition parameter relates, for example, to the degree of T_1/T_2 contrast in a magnetic resonance

20   image. The multi-dimensional data set is formed from the individual images as if it were by arranging the individual images so as to be "stacked one onto the other" or "arranged one behind the other" in the direction of succession. The multi-dimensional data set thus formed assigns data values, such as brightness values, from the individual images to positions in the multi-dimensional space. The dimension of the multi-dimensional space is exactly one larger

25   than the dimension of the images. The images are, for example, two-dimensional images; in that case the multi-dimensional space is three-dimensional. It is also possible to use images in the form of volume data, for example, 3D-MR reconstructions or 3D reconstructions derived from X-ray computed tomography. The multi-dimensional space is then four-dimensional. The positions in the multi-dimensional space comprise the position in the direction of

30   succession and the position in the image for the relevant position in the direction of succession. In accordance with the invention a slice through the multi-dimensional data set is reconstructed along the cut plane. The cut plane is a plane in its simplest form, but surfaces that are curved in the multi-dimensional space are also feasible. The slice represents the data values in the multi-dimensional data set, that is, data values arranged along the cut plane. A

suitable technique for the reconstruction of the slice is, for example, the so-called "multi-planar reformatting". According to that method it is also possible to calculate, for example, by interpolation, data values in the multi-dimensional data set for positions in the direction of succession that lie between positions of succession between two successive images.

5   The cut plane is not chosen to be oriented perpendicularly to the direction of succession; in that case the slice would actually come down to choosing the image for the relevant position of succession. Furthermore, the cut plane can be chosen in conformity with the situation of the region of interest in the one or more images. When a priori information is known concerning the regions of interest to be located, the cut plane can be oriented and positioned

10   on the basis of said a priori information.

It has been found that the region of interest in the one or more images is particularly clearly reproduced in the slice. It is notably when said region of interest is detected each time in a plurality of individual images that the region of interest can be simultaneously determined in the respective images on the basis of the slice. The correlation

15   between the region of interest in the successive images, for example, the time correlation, becomes very manifest in the slice that is situated at least partly in the direction of succession, for example, along the time axis.

These and other aspects of the invention will be further elaborated on the basis of the following embodiments that are defined in the dependent claims.

20   Preferably, the region of interest is segmented from one or more individual images on the basis of the reconstructed slice along the cut plane. Segmentation of the region of interest means that said region of interest is separated from the remainder of the relevant image. It has been found that the boundaries of the region of interest in each of the individual images appear much more clearly from the reconstructed slice along the cut plane. The edge

25   of the region of interest often is locally vague in an individual image. Despite vagueness at the edge of the region of interest in several of the successive images, however, it has been found that considerable correlations exist between the brightness values of the successive images at the area of the vagueness. Because of these correlations, a distinct edge is visible in the reconstructed slice. This edge can, therefore, be readily located in the reconstructed slice.

30   Using the edge in the reconstructed slice, the edge of the region of interest that is usually much vaguer in the images themselves can be determined in separate images and the region of interest can be segmented from the individual images.

The invention offers good results notably for cardiological applications of the magnetic resonance imaging method, especially for angiography; such results are achieved in

particular for the segmentation of the image of the myocardium (the heart muscle) from the image of the surrounding tissue. For this MR cardio application the region of interest is, therefore, a series of temporally successive magnetic resonance images of the myocardium. The degree of perfusion of the myocardium can be accurately determined on the basis of

5   accurate segmentations of the regions of interest, that is, the segmentations of the myocardium. It has even been found that it is possible to determine whether there are regions in which the perfusion is disturbed or even seriously disturbed. An accurate diagnosis in respect of a suspected infarct can be made on the basis of the existence of such regions of poor diffusion and of their situation. It is to be noted that the result of the image processing

10   operation in accordance with the invention constitutes a useful technical aid for a cardiologist in making such a diagnosis.

Preferably, in accordance with the invention a plurality of slices is taken along different reconstructed cut planes through the multi-dimensional data set. Respective edges are tracked in the individual slices. The edge of the region of interest in the individual images

15   can be determined on the basis of the locations, in the individual images, of the tracked edges in the respective reconstructed slices. For example, it has been found that each time a part of the boundary of the region of interest in each of the images is derived from individual reconstructed slices. Subsequently, the respective positions are determined from the individual reconstructed slices of the boundary in a relevant image. This point is each time

20   the point of intersection of the boundary in the relevant image and the edge in one of the cut planes. Thus, a number of positions of the boundary of the region of interest is determined, that is, one for each (or a number of, preferably the majority) of the cut planes in the relevant image. The complete boundary of the image of interest is derived from these positions, for example, by interpolation. It is also very well possible to link these positions of the boundary

25   by hand. The result is further enhanced by utilizing a priori information, concerning, for example, the known shape of the region of interest, in deriving the complete boundary.

These and other aspects of the invention will be described in detail hereinafter, by way of example, on the basis of the following embodiments and with reference to the accompanying drawing; therein:

30   Figs. 1 and 2 illustrate the method in accordance with the invention, and

Fig. 3 illustrates the extraction of the boundary of the region of interest while utilizing a plurality of reconstructed slices.

The Figs. 1 and 2 illustrate the method in accordance with the invention. Fig. 1 is notably a representation of the multi-dimensional data set (in this case a 3D data set) 2 that

is composed of the individual images 1 that are arranged one behind the other in the direction of succession 6. This means that the images that relate to a later instant in time are shown further forwards in Fig. 1. The cut plane 3 extends approximately perpendicularly to the plane of drawing in Fig. 1. The reconstructed slice along the cut plane 3 is shown in a simple

5   form in Fig. 2. For the sake of simplicity, the region of interest 7, 8, 9 is indicated in a few (three) individual images only.

Fig. 2 is a simplified representation of the slice along the cut plane 3. Fig. 2 notably shows the slices in the cut plane of the region of interest as shown in the three individual images of Fig. 1. Fig. 2 also shows that the region of interest in the reconstructed

10   slice is clearly separated from image information outside said region of interest. Notably distinct edges 22, 23 can be seen in the reconstructed slice. The edge of the region of interest in each of the individual images 1 is determined on the basis of the distinct edges 22, 23 in the reconstructed slice.

Fig. 3 illustrates the extraction of the boundary of the region of interest while

15   utilizing a plurality of reconstructed slices 3 to 5. For the sake of simplicity, Fig. 3 shows the region of interest in one of the individual images 1 only. Each of the reconstructed slices along the respective cut planes has two points of intersection 24 with the edge of the region of interest. The edge of the region of interest is accurately determined by interpolation between the points of intersection 24. Preferably, this interpolation takes into account a priori

20   known information concerning, for example, the shape of the region of interest. For example, this a priori information concerns the expected irregularity or smooth course of contours in the images, information (static or not) concerning the expected shape of objects reproduced in the images, for example, the shape of the region of interest, and expected patterns that occur strikingly often in the vicinity of the region of interest.